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WORKING PAPER ON A CASE STUDY ON THE TRANSFER OF SPACE TECHNOLOGY

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An assessment is made of the role of technology transfer in Soviet space technology. The analysis is based on first-hand knowledge and insights available as a result of the Apollo-Soyuz Test Project. It is concluded that technology transfer has not had a significant role in the historical development of Soviet space technology. However, it may play an increasingly greater role in the future.

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ABSTRACT

This report presents an assessment of the role of technology transfer in the historical development and possible future progress of Soviet space technology. The analysis is based on first-hand knowledge and insights about Soviet space technology that are now available as a result of the Apollo-Soyuz Test Project. It is concluded that technology transfer has not had a significant role in the historical development of Soviet space technology. However, it may play an increasingly greater role in the future. There appears to be a willingness on the part of the U.S. to facilitate (to some extent) the transfer of its technology. Correspondingly, the Soviets appear to have come up against some severe technological problems and shortcomings and now view technology transfer as a viable means of solving or circumventing them.

I. INTRODUCTION

In support of efforts to develop methodologies to assess technology transfer in the U.S.S.R. whether developed externally such as by the U.S. or internally such as by the U.S.S.R. itself, it is of interest to consider as a case study, the Apollo-Soyuz Test Project. The objectives of this case study are to learn as much as possible from the available Apollo-Soyuz information about the role of technology transfer in the historical development and the possible future progress of Soviet space technology. If such a role can be identified then it is also of interest to examine the processes by which foreign technology has been or may be assimilated and utilized in the Soviet space program and to assess the implications.

Because of its many different aspects, any of several different meanings may be attached to the term "technology transfer". Therefore, it is desirable to present some definition of how it is used in this report. Here, the primary emphasis is on the technical aspects of technology transfer including hard evidence in the form of systems, components, design practices, manufacturing techniques, etc., of the acquisition and successful application of one nation's technology by another nation. Merely having knowledge about another nation's technology without putting that knowledge to some practical use is not considered to be technology transfer. The active seeking of such knowledge, however, is considered to be an indication of intent or desire to accomplish technology transfer.

Other aspects of technology transfer (e.g., social, political, and economic) are to be analyzed in future studies of broader scope to which the present study will provide input. Consequently, these aspects are only considered here whenever they are deemed especially pertinent.

Technology transfer is not new to United States-Soviet relations and the history of the relations show that the Soviets have a great capacity for assimilating foreign technology. Throughout the first half of this century, both before and after the communist revolution, U.S. technology (e.g., railroad, electrification, metallurgy, automotive, farm machinery, etc.) was exported to the Soviet Union (Russia) to assist its drive toward industrialization[(1)*]. During World War II, the Soviets gained much from their

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* Superscript numbers in parentheses refer to items in the Reference List.

exposure to U.S. weapons technology. A spectacular example of technology transfer occurred when an American B-29 bomber that made a forced landing in the Soviet Union was copied and produced by the Soviets as the TU-4. The monumental case of technology transfer, however, was the Soviet acquisition of German rocket technology. During the cold war era after WWII, most western nations imposed sanctions against the transfer of technology to the Soviet Union. However, there were several known and suspected cases of surreptitious and clandestine transfers of technology (e.g., atomic weapons technology). Having been initiated during this era and couched in political and strategic competition, the space programs of both nations have been the focus of considerable interest and some controversy with regard to technology transfer. Consequently, the subject of technology transfer arises quite naturally in connection with the Apollo-Soyuz Test Project.

It should be emphasized at the outset, however, that technology transfer is not an objective of the Apollo-Soyuz Test Project and, in fact, the project is organized and conducted to minimize the transfer of technology in either direction[2]. For the present study, the primary interest is not the project itself but rather, the first-hand knowledge and insights about Soviet space technology that are now available as a result of the project. Prior to the Apollo-Soyuz Test Project, such knowledge was rare outside the Soviet Union's own space community (which because of the extreme security imposed by the Soviets, even excluded a major part of their scientific and engineering communities at large). However, during the course of the Apollo-Soyuz Test Project there were exchanges of information and for the first time, reciprocal visits to pertinent space program facilities and inspections of space program hardware. Also for the first time, space program personnel of both nations had opportunities to meet their counterparts face-to-face and to cooperate in their own areas of specialization in the planning and conduct of this joint mission. As a result of this experience, Soviet space technology is now better known and better understood. Correspondingly, the possibilities of technology transfer can be better assessed.

The role of technology transfer in the historical development of Soviet space technology is analyzed in Section II of this report. Since the greatest body of information derived from the Apollo-Soyuz Test Project concerns manned spacecraft technology, or, more specifically, the Soyuz spacecraft, this aspect of Soviet space technology is emphasized. Other aspects of space technology such as instrumentation, electronics, and computer technology are incorporated in the discussion as appropriate. Part 1 of Section II presents a description of Soyuz and a comparative evaluation of Soviet and U.S. manned spacecraft technology. Part 2 of Section II presents a comparative evaluation of the Soviet and U.S. docking systems used for the Apollo-Soyuz mission. The evidences concerning the historical role of technology transfer are developed on the basis of these comparative evaluations. Part 3 of Section II presents an assessment of the evidences and their implications.

Section III of this report presents a discussion of the possible role of technology transfer in the future progress of Soviet space technology.

Section IV presents the conclusions of this study.

II. THE ROLE OF TECHNOLOGY TRANSFER IN THE HISTORICAL DEVELOPMENT OF SOVIET SPACE TECHNOLOGY

In this section, specific evidences of the transfer of U.S. space technology are sought by analyzing selected examples of Soviet space hardware and comparing them with U.S. hardware. Part 1 deals with manned spacecraft. Part 2 deals with the Apollo-Soyuz docking systems. The findings are evaluated in Part 3.

1. Manned Spacecraft Technology

As a result of the Apollo-Soyuz Test Project, new information has become available which provides a basis for an objective analysis of the role of technology transfer in the historical development of Soviet space technology. For the most part, the new information concerns the Soyuz spacecraft. This information is considered to be particularly appropriate to the analysis of technology transfer because:

(1) manned spacecraft technology is generally representative of the whole spectrum of Soviet space technology and

(2) the Soyuz is representative of approximately the past decade of the evolution of Soviet space technology.

Manned spacecraft technology incorporates areas such as spacecraft structures (including fabrication and materials technologies), guidance and control (including instrumentation, electronics, reaction control systems, etc.), life support, spacecraft power, and mission support (including boosters, ground support equipment, computer utilization, etc.). The Soyuz spacecraft is the second generation of Soviet manned spacecraft (assuming that Voskhod was not a new vehicle but rather, a direct derivative of Vostok). It was designed during the mid-1960's. Its first manned flight was in 1967. Cosmonaut Komorov was killed in that flight when the reentry parachute failed and the modification of Soyuz began immediately afterwards. This process of modification and refinement has continued to the present time.

A description of Soyuz is presented next and subsequently, Soyuz is compared with the U.S. Gemini spacecraft to evaluate the possibilities of technology transfer.

a. Soyuz Technology

Soyuz was designed to support the on-going Soviet program of manned spaceflight which currently emphasizes earth-orbital workshop missions and earth-orbital station missions. To support these kinds of missions, the Soyuz features an Orbital Module (space workshop) and a Descent Module (command module) for the crew and crew activities and an Instrument Module (service module) which provides the required operational capabilities. A schematic diagram of Soyuz is shown in Figure 1.

(1). Orbital Module

The Orbital Module serves as an on-orbit workshop in which the crew conducts scientific experiments and other activities including eating and resting. It is only used during the orbiting phase of a mission while it remains attached to the Descent Module. Upon completion of a mission, the Orbital Module is detached from the Descent Module and abandoned. The Orbital Module is a welded pressure-vessel type structure with hemispherical ends and a short cylindrical insert[3]. Superficially, the Orbital Module resembles the first generation Soviet spacecraft, Vostok and Voskhod, and probably utilizes the same basic structural design with different outfittings.

(2). Descent Module

The Descent Module is the command section of the Soyuz spacecraft and is occupied by the crew during launch and reentry and during on-orbit maneuvers. The Descent Module consists of flared, conical structures with a hemispherical cap (incorporating an attachment ring and hatch for the Orbital Module) at one end and a blunt heat shield at the other end[3]. The Soviets have not revealed any of the structural details about the Descent Module; however, presumably, it is a welded pressure-vessel-type structure also.

SOYUZ

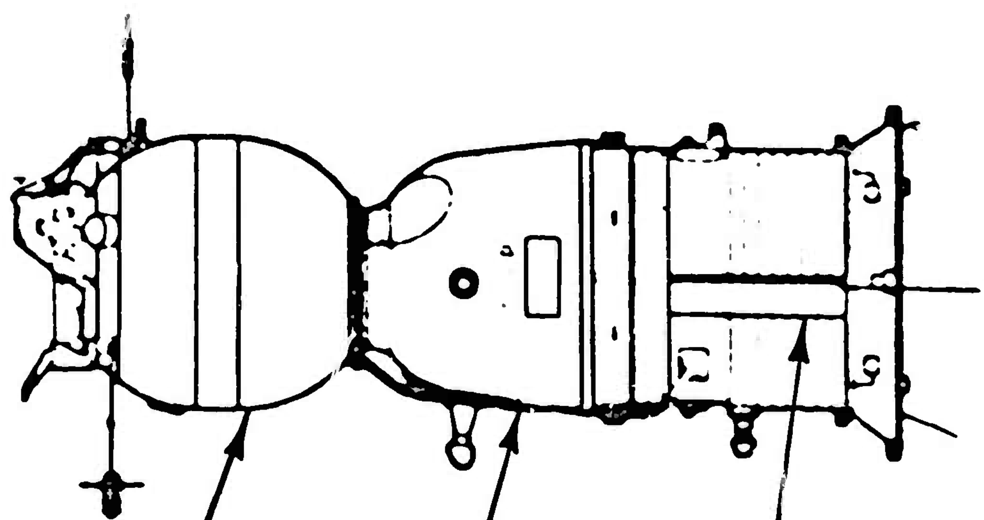

FIGURE 1. SOYUZ SPACECRAFT

(3). Instrument Module

The Instrument Module incorporates the propulsion systems, electrical power system, life support system, communications system, etc. It is a cylindrical structure with a conical flare and incorporates a space truss assembly which provides mounting points for the propulsion engines and the solar panels and attachment points for the Descent Module. The main propulsion system, used for on-orbit maneuvering and for reentry, includes a single-chamber engine with 417 kg thrust and a back-up, two-nozzle engine with 411 kg thrust. The approach and orientation propulsion system, used for rendezvous and docking and for spacecraft control maneuvers, includes 14 thrusters of 10 kg thrust each and 8 thrusters of 1 kg thrust each. The spacecraft attitude control propulsion system incorporates 6 thrusters and is used in conjunction with the approach and orientation propulsion system for spacecraft attitude control[3].

The electrical power system of the Soyuz spacecraft uses two solar panels as the main power supply and includes a primary and back-up set of chemical storage batteries. The system operates at a nominal voltage of 27 (+7, -4) volts. The electronic equipment and instruments associated with the spacecraft guidance and control system, the radio communications system and the life support system are mounted in hermetically sealed compartments which comprise a short cylindrical segment (called the "assembly module") located in the front part of the Instrument Module[3].

(4). Guidance and Control System

The guidance and control system includes those instruments, equipment, systems, and subsystems that enable the Soyuz spacecraft to perform its design mission requirements including attitude control, on-orbit maneuvering, rendezvous and docking, and reentry. These operations are controlled from the Descent Module either by the crew (manually or automatically) or remotely by radio uplink from the ground (the Soyuz can be flown unmanned). Standard operations, consisting of a series of discrete commands, may be performed manually (each command may be executed manually) or automatically. The automatic execution of a pre-programmed series of commands is accomplished by selecting a program and then using the spacecraft timer to drive the command sequencer, an electrical switching device which sends command signals through logical switching circuits to the various propulsion subsystems and other such equipment which produce the desired actions and operations[3].

Figure 2 shows a simplified schematic of the Soyuz guidance and control system. Command signals required for orientation and attitude control of the Soyuz spacecraft are provided automatically by several electro-optical devices or, they can be input by the crew using manual techniques. The vertical alignment of the spacecraft is monitored by an Infrared Vertical Sensor and by a Sun Sensor[3]. The Infrared Vertical Sensor detects the infrared radiation from the earth and the earth's atmosphere in order to locate the horizon. Using this as a reference, the device measures the misalignment between the spacecraft vertical axis and the local vertical. The output signals from the Infrared Vertical Sensor are converted into command signals for automatic roll and pitch maneuvers. The Sun Sensor is also used to monitor the vertical alignment of the spacecraft. It can detect a misalignment between the spacecraft vertical axis and the sun line-of-sight with a tolerance of ±6 degrees. Manual techniques may be used by the crew to monitor the spacecraft attitude condition using a periscope with split optics to view both the horizon and the earth surface directly under the spacecraft.

The direction of the spacecraft longitudinal axis relative to the orbital velocity vector is monitored by Ion Sensors[3]. These are electrical devices (Faraday cups) which measure the charged particle flux incident on the spacecraft as it moves through the space plasma. The Ion Sensors are located at three different locations on the external surface of the spacecraft. The differential readings from pairs of Ion Sensors are compared and command signals are generated for maneuvers about the pitch and yaw axes.

The Soyuz spacecraft incorporates two Inertial Platforms for spacecraft attitude reference[3,4]. One of the inertial platforms is located in the Instrument (service) Module and one is located in the Orbital Module. Both platforms operate simultaneously* and incorporate two free gyros with two gimbals and three rate gyros. The inertial platforms incorporate angular rate

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* According to a report in Aviation Week and Space Technology, the inertial platforms are turned on just before a maneuver and then turned off when the maneuver is completed to conserve electrical power. If that is the case, then it can only serve as a relative and not an absolute inertial reference platform[4].

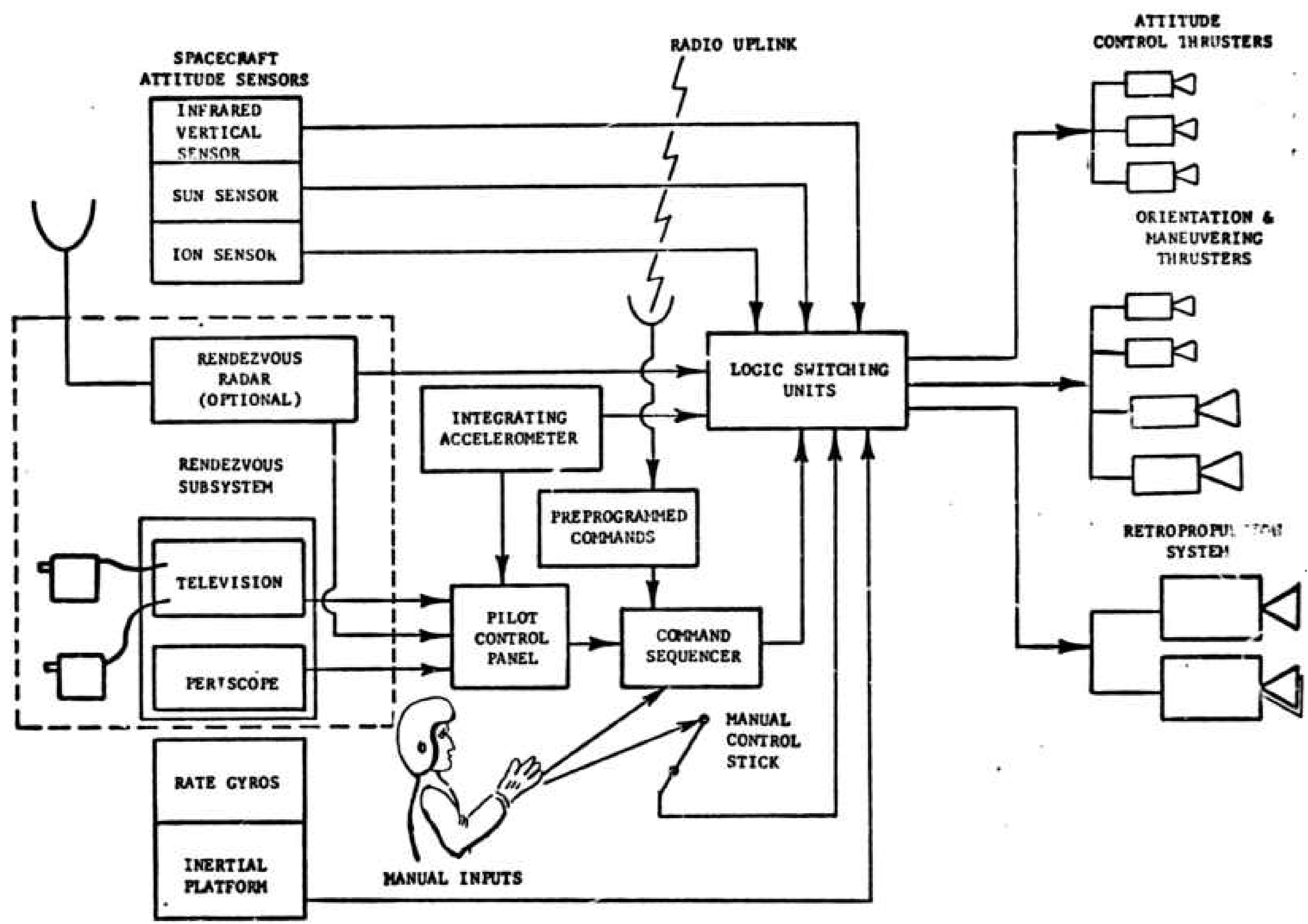


FIGURE 2. SIMPLIFIED SCHEMATIC OF SOYUZ GUIDANCE AND CONTROL SYSTEM

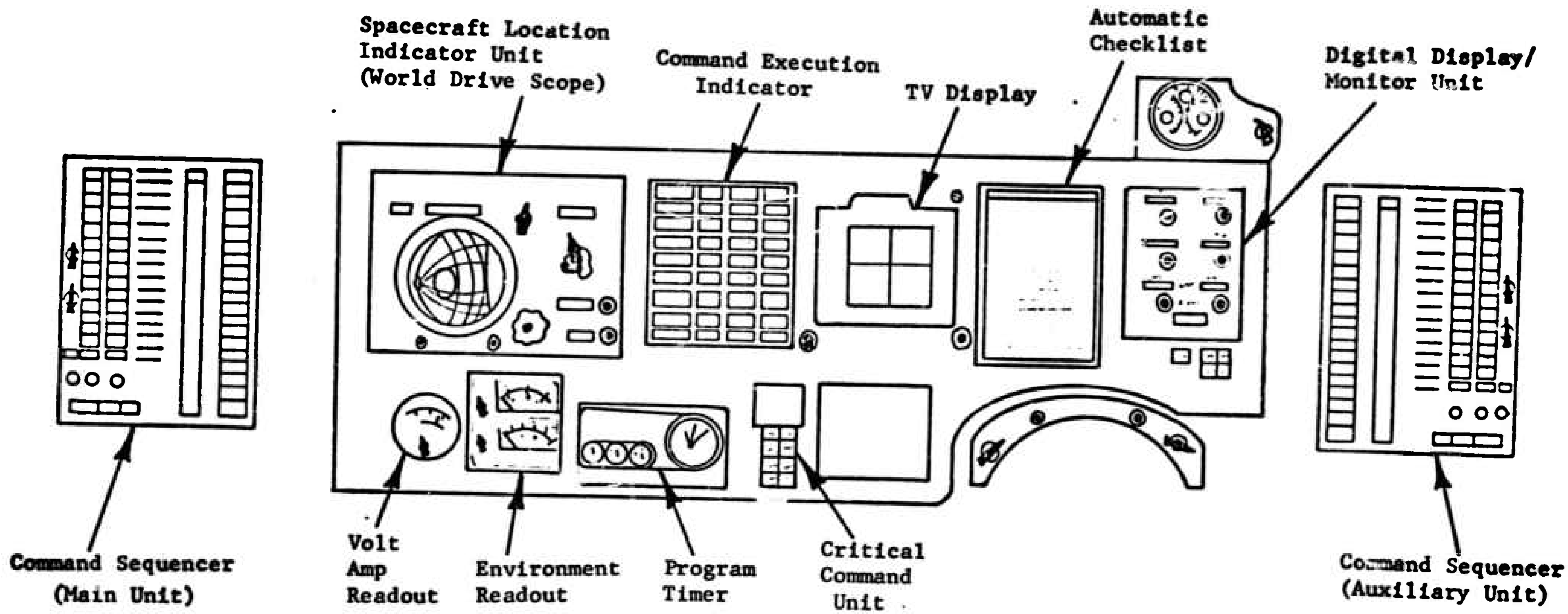
sensors and angular deflection sensors (analog integrators) to provide selected spacecraft attitude holds from zero to 360 degrees with a maximum deviation of ±8 degrees. If the deflection exceeds ±8 degrees during the automatic attitude control mode an emergency signal is generated and the orientation thruster system is automatically disabled.

Three (triply redundant) Integrating Accelerometers are installed in the Instrument Module to provide measurements of velocity increments along the spacecraft longitudinal axis(3). An electronic logic unit in the Instrument Module accepts the readout of all three integrating accelerometers and chooses (according to pre-set criteria) the best value by voting. The output is displayed by a mechanical digital readout located on the main instrument panel in the Descent Module.

One of the key components in the Soyuz command and control system is the Switching Logic Unit located in the Instrument (service) Module(3). This device processes input command signals and generates and distributes output signals to the appropriate subsystems and equipment which cause the command to be executed. The switching logic unit is redundant so that a single failure does not cause any malfunction. It is powered from three separate electrical bus bars with separate overload protectors.

The control center of the Soyuz spacecraft is in the Descent Module and includes the main instrument panel and two identical command sequencers located beside the main instrument panel, one on the right and one on the left. Figure 3 is a sketch of the main instrument panel indicating the relative locations of major components including:

- The "world drive scope", a ground position indicator
- Electrical system monitoring instrument (volt-amp meter)
- Environment system monitoring equipment
- The spacecraft timer
- A program monitoring indicator which displays program checklists and indicates program execution
- A panel of caution and warning lights
- A multifunction cathode ray/TV scope
- Digital readouts for monitoring velocity increments and propellant supplies
- A series of critical command switches(3).



MAIN INSTRUMENT PANEL

FIGURE 3. SOYUZ MAIN INSTRUMENT PANEL AND COMMAND SEQUENCERS(3)

The command sequencers (see Figure 2) incorporate 16 program selection keys with corresponding verification lights and 24 numbered keys for the selection of appropriate subfunctions.

For rendezvous and docking missions, the Soyuz is outfitted with a range and range-rate indicator and a radar system (refer to Figure 2). This equipment is not included in the spacecraft to be flown in the Apollo-Soyuz Test Project because the Soyuz will assume the role of a passive target in that mission.

b. Comparative Evaluation of Soyuz and U.S. Manned Spacecraft Technology

In principle and function, the Soyuz spacecraft is similar to U.S. manned spacecraft in some respects and quite different in others. On the basis of superficial appearances alone, it is immediately obvious that the Soyuz is quite different from Apollo and considerably less sophisticated; but, because Soyuz was designed for earth-orbital missions and Apollo for lunar missions, these differences are to be expected. Perhaps a better basis for evaluating the possibilities of technology transfer would be to compare Soyuz with Gemini. The design mission capabilities for these two spacecraft are comparable and they were developed sequentially. The Gemini Program was started around 1961 and included a series of 12 manned flights between 1964 and 1966[5]. Soyuz was introduced in 1967 (first manned Soyuz flight) and has remained in use to the present time with more than 20 manned and unmanned flights to its credit. This combination of circumstances (compatible mission capabilities and sequential development) are ideal from the standpoint of considering the possibilities of technology transfer because it may be assumed that much of the U.S. technology that went into the design of Gemini would have been a matter of public record during the time that the Soviets were designing and developing Soyuz. Consequently, the Soviets would have had knowledge of the Gemini technology and if they desired, would have had the opportunity to apply that knowledge to the Soyuz program.

Upon comparing Gemini and Soyuz, the initial observation about basic similarities and differences still holds. The similarities, however, appear to derive from the fact that any spacecraft must be designed in accordance with certain fundamental physical principles and engineering considerations that are the same or similar regardless of who does the design. The differences appear to be associated with different basic design philosophies and different ways of doing things.

Externally, the Soyuz and Gemini spacecraft show no major similarities except, perhaps, that the shape of the blunt heatshield on the Soyuz descent module resembles that of the Gemini heat shield. This shape, of course, is dictated by basic aerothermodynamic considerations. The external shapes and the structures of the two vehicles (i.e., Gemini and the Soyuz Descent Module) are substantially different due for the most part to the different structural design approaches and design constraints (e.g., launch vehicle performance capabilities).

The Gemini spacecraft was a semimonocoque-type structure (skin, strings, ribs, and bulkheads) as was the Mercury and Apollo spacecraft[5]. Accordingly, all of the U.S. spacecraft show a direct lineage from U.S. aircraft design practices. In the U.S., of course, the aircraft industry and the spacecraft industry are virtually one and the same, the U.S. aerospace industry. In addition, U.S. experimental rocket aircraft programs such as the X-15 project and conceptual design programs such as Dyna Soar played a major role in the evolution of the U.S. manned spacecraft design philosophy.

The Soviet design philosophy, however, appears to have evolved from a different kind of origin. The welded pressure-vessel-type structures employed in Soyuz, as well as in Vostok and Voskhod, do not appear to have derived from Soviet aircraft technology and the Soviets did not have the "aerospaceplane" experience to draw from as did the U.S.*. Instead, it appears that the Soviet spacecraft design approach may have evolved from their design experience with sounding rocket capsules or with the goldolas used for high-altitude balloon flights. During the 1950's, for example, the Soviets conducted large programs of sounding rocket and high-altitude balloon flights and eventually drew from this experience to develop the bail-out recovery procedure that was used in the Vostok program[7].

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* Some early rocket powered airplane experiments were conducted by S. P. Korolev, the Soviet Chief Designer, in the 1930's and 1940's[6].

The extensive use of welding technology for spacecraft fabrication is one of the most distinctive and technically advanced features of the Soviet structural design approach and the Soviet application of welding technology is appraised highly by U.S. experts[8]. Their fabrication techniques include automatic and semiautomatic spot welding and butt welding for which the symmetrical shapes of their spacecraft shells are particularly appropriate. Their inspection techniques include ultrasonic tests, continuous X-ray inspection, and helium sniffing and all welded shells are subjected to a rigorous series of static and dynamic tests to verify their structural and pressure integrity[9]. Thus, the Soviets appear to have developed their spacecraft structural design approach along independent lines under the major influence of their own native technical experience and capabilities. In this area, it does not appear that the transfer and adaptation of U.S. technology has ever been attempted or even seriously considered by the Soviets.

An "internal" comparison between Soyuz and Gemini is somewhat more difficult than the preceding "external" comparison. This is partly because there is less available information about the systems and subsystems "inside" Soyuz and partly because there is little direct knowledge about the Soviet design philosophies which guided their development. In considering this matter relative to the basic issue of technology transfer, attention will be focused on the Soyuz guidance and control system. But first, it is appropriate to mention the distinctive Soviet approach to spacecraft electric power and life support systems. In the Soyuz design, the Soviets continued to follow the solar array approach which they pioneered in their earliest Sputnik flight[3,7] and there is no indication that they have attempted to introduce fuel cells such as have been used in Gemini and Apollo. Likewise, the Soviets developed a life support system based on providing a "sea-level" type environment and have continued to follow this approach[3]. In both of these cases, the United States and the Soviet Union chose different design paths to achieve the same end and up to the present time, no technology transfer appears to have occurred.

The rudimentary descriptive information that is available about the Soyuz guidance and control system was summarized earlier in this report. On the basis of the available information, it appears that the Soyuz system is similar to, but somewhat less sophisticated and less versatile than the guidance and control system of Gemini. For example, both spacecraft use similar kinds of attitude sensors and inertial platforms to generate the same kind of command signals for the spacecraft attitude and orientation control*. However, the guidance and control system of Gemini incorporated a digital computer for analyzing and processing the command signals whereas the Soyuz system apparently incorporates systems of hard wired logic and switching circuits for these purposes[3,5].

The advantage of using an on-board computer (or, in the case of Apollo, three on-board computers) is greater flexibility of spacecraft operations and increased piloting capabilities for the crew which, of course, is a fundamental aspect of the U.S. spacecraft design philosophy[5]. In comparison, the Soviet design philosophy as reported by Cosmonaut/Designer K. Feoktisov, places the greater emphasis on remote control (radio uplink) and automated operation and lesser emphasis on crew participation[11]. The Soyuz, for example, can be operated unmanned (as could Vostok and Voskhod) whereas in the manned versions of Gemini, only the launch and reentry phases could be flown in a completely automatic mode. All other phases of flight required some manual control; and even for reentry, automatic control was optional[5].

In addition, the control panel displays and readouts in the respective spacecraft give some indication about the basic control system design philosophies. The crews of U.S. manned spacecraft, being an integral link in the spacecraft control system, are provided with copious displays and readouts which together with the spacecraft computer enable them to operate almost autonomously in space and to fly complex maneuvers such as controlled aerodynamic reentries during communications black-outs or, in the case of Apollo, lunar landings and takeoffs. In contrast, the control panel of the Soyuz spacecraft incorpotates relatively few, and by U.S. standards, rudimentary instruments and readouts. For example (refer to Figure 2), there is no

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* Typically, U.S. spacecraft sensors operate at almost an order of magnitude less tolerance than those reported for the Soviet spacecraft sensors[10]. It is not known whether the greater tolerances of the Soviet sensors represent technological limitations on design preferences.

spacecraft attitude readout even though the raw data is readily available. The spacecraft position indicator (world drive scope) is of little or no value for precision navigation. The spacecraft electrical system is monitored by a conventional looking volt-amp meter. Timing functions are accomplished using a clock and three stop watches. Velocity changes and propellant residuals are read-out on mechanical digital counters and electronic digital counters are not used at all. Thus, the Soyuz crew is provided with only limited information and their functional role is correspondingly constrained. It is a mystery why the Soviet spacecraft designers have not made even the most obvious applications of their own aircraft technology to improve these circumstances.

The substantial differences between the U.S. and Soviet spacecraft guidance and control systems indicate that little if any technology transfer has occurred in this area. Apparently, the different design philosophies represent something of a barrier to technology transfer. In addition, the strategic importance of guidance technology makes it somewhat sensitive and this is probably a major factor in limiting technology transfer.

It is likely that there are other factors closely related to design philosophy which also partly account for the apparent lack of technology transfer in the area of guidance and control. These factors are associated with the basic issue of needs (e.g., design requirements) versus technical capabilities to satisfy those needs. In 1968, Wukelic, et al., produced a survey of the general field of Soviet space instrumentation from which it may be observed that the Soviet instrument design philosophy was very conservative and the engineering practices were typically "Soviet"(7). In the past, it appears that Soviet designers only demanded low to modest extrapolations of their native state-of-the-art which, by their own standards, were considered adequate for the kind of missions that were performed. Under these circumstances, there would have been little or no impetus for technology transfer. Only recently have there been indications of change: now, when the Soviets find themselves significantly lagging western technology in especially critical or strategic areas (e.g., multi-spectral scanners for relaying digitized images from orbiting spacecraft), they have not hesitated to pursue whatever technology transfer options that are available to them(12).

It was observed during the course of the Apollo-Soyuz Test Project that the Soviets do not make as extensive use of computer computation and simulation techniques in connection with their space program activities in the United States[13]. For example, in the extensive spacecraft safety assessment investigations conducted by both nations the U.S. used a technique called "SNEAK" circuit analysis which effectively combines man and the computer to detect deficiencies in electrical circuit designs[14]. The computer, when programmed with the circuit design data, creates printed networks that treat all interfaces equally in the normal and abnormal operating modes. Using these printed networks and the known characteristics of improper circuits, latent defects can be readily identified by manual searches. The Soviets, however, performed the entire safety assessment investigations manually and mechanically. Still another example concerns a U.S. request for additional information on the orbital state vectors and dispersions for the Soyuz spacecraft at certain times after the Soyuz launch and before the Saturn/Apollo launch in order to perform real time trajectory and launch window analyses in case either of the orbits are non-nominal. The Soviets, however, could not provide the data because, to obtain them, would require a change in their computer program and a change in the busy schedule of their control center activities[15]. Consequently, the U.S. will obtain the data through their own ground tracking network and make the necessary computations at the U.S. flight control center. Apparently, the Soviet capabilities for doing real-time analyses and interactive programming also are somewhat less than those of the U.S.

2. Apollo-Soyuz Docking System

In further consideration of the possibilities of technology transfer attention will be focused next on the Apollo-Soyuz Docking Systems. The docking systems are the only major new hardware items that were developed bilaterally for the Apollo-Soyuz mission*. As such, they offer the only significant opportunity for technology transfer to have occurred in connection with that mission.

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* A docking module which serves as the air lock and transfer tunnel between the two spacecraft was designed independently by the U.S.

Early in the Apollo-Soyuz project, the U.S. and Soviet engineers charged with the responsibility of designing and developing the compatible docking systems agreed to a common design philosophy[16]. Essentially it was to adopt a common docking system concept, to specify the minimum number of required parameters to assure compatability, and then proceed independently with the design. The concept that was agreed to is referred to as a peripheral, and androgynous-type docking system meaning that all elements that come into contact during docking are distributed symmetrically with respect to the axis of inverse symmetry. It was agreed that either system would be able to serve as the active system or the passive system during docking, that both systems would be capable of multiple use and that undocking under nominal or emergency conditions could be accomplished from either spacecraft. The design specification include statements about tolerances and limits, attenuation of forces and loads during docking procedures, alignment, instrumentation, and safety.

Figure 4 shows the basic design of the docking systems for the Apollo-Soyuz mission. The U.S. and Soviet docking system designs turned out to be identical in all respects where they had to be identical and different where they could be different. The essential difference is in the retract mechanism which draws the two spacecraft together (into the "hard" docked configuration) after an initial capture has been made.

The U.S. designed docking system features a cable retract system derived from Apollo technology[16]. It incorporates three electric motors which drive three cable winding mechanisms with electromagnetic clutch-brake units. Each of the three mechanisms can operate independently in the forward or reverse direction to produce the differential motion to bring the two spacecraft into proper alignment as they are being drawn together. Instead of cables, the Soviet design incorporates six screw drives (helically geared rods) with universal joints[16]. The rods are driven by electric motors through differential gears and electromagnetic clutch-brake units. Both designs incorporate sensors to detect misalignments and operate in such a way that the spacecraft are brought into proper alignment as they are being drawn together.

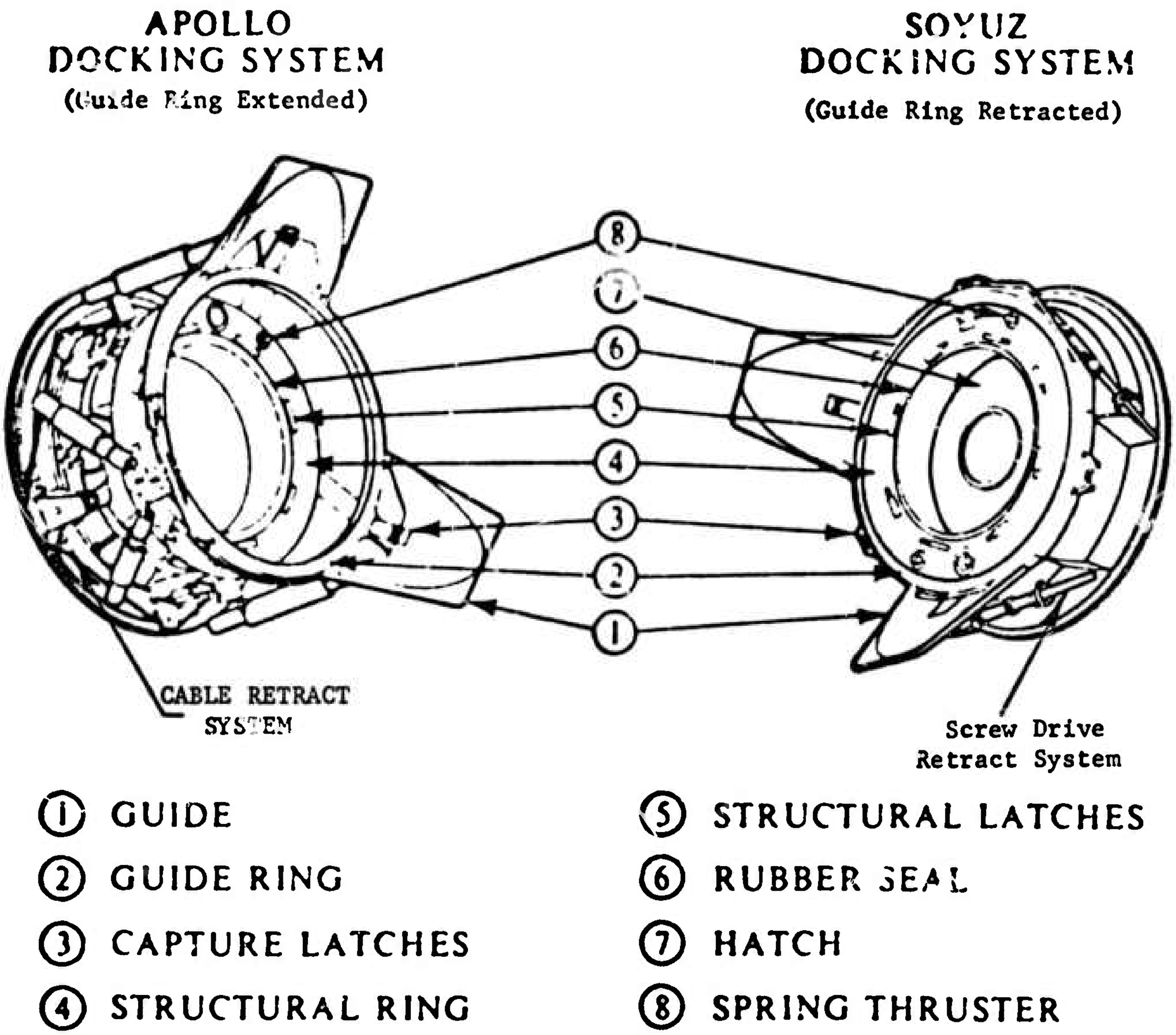

FIGURE 4. PERIPHERIAL - ANDROGYNOUS DOCKING SYSTEMS FOR THE APOLLO - SOYUZ TEST PROJECT(16)

In the joint compatability tests of the U.S. and Soviet docking systems there was another indication of the limited use of computers by the Soviets. In the U.S., computer simulation is used to compute out gravitational effects whereas the Soviets used a cable suspension system to compensate for gravitational effects[8].

As indicated previously, the design and development of the compatible docking systems offered, perhaps, the best opportunity for technology transfer to occur in connection with the Apollo-Soyuz Test Project. It should be emphasized, that the initial design and development activities were contemporary with the Soyuz XI accident (July, 1971) in which three cosmonauts were killed, due to a malfunctioning hatch, upon returning from a rendezvous and docking mission with the Soviet space station, Salyut. Therefore, there was a potential need as well as a potential opportunity for the Soviets to acquire and implement some U.S. technology. However, the Soviets stuck with their own design approach and no technology transfer appears to have been attempted.

3. Assessment of the Historical Case for Technology Transfer

The new knowledge and insights about Soviet space technology resulting from the Apollo-Soyuz Test Project give no indication that the Soviets have attempted or accomplished any significant transfer of U.S. space technology. The technology that went into the design and development of Soyuz is distinctively "Soviet". It is characterized by a design philosophy and by designs, developments, and techniques that are essentially "Soviet ways of doing things" as readily distinguishable from "U.S. ways of doing things". To the extent that Soyuz technology is representative of the entire spectrum of Soviet space technology of the early-to-mid-1960's, it appears that Soviet space technology on the whole also was distinctively "Soviet".

These results are somewhat surprising in view of the traditional openness of the U.S. space program which, for many years, was the basis for concern that at least some U.S. technology would have been appealing to the Soviets and would have been essentially free for the taking. Indeed, the Soviets have always displayed an intent interest in the U.S. space program, its plans and its technical literature, and possibly could have capitalized on U.S. technology. Apparently, however, they did not choose to do so and it is pertinent to consider why.

During the early years of the space era, the Soviets had sound reasons for essentially ignoring the U.S. space technology transfer options that were available to them. After World War II, the Soviets initiated a crash effort to capitalize on captured German rocket technology and as a result, developed native capabilities which they considered to be the most advanced in the world during that time. The space program that evolved from this technology was equally advanced for its time and was also considered to be superior to anything that could be obtained from the U.S.

In addition, there were political and ideological reasons for rejecting technology transfer which, in the long run, probably outweighed the preceding technological reasons. With the on-set of the cold-war politics that characterized the post-World War II era, the Soviets launched a multi-faceted drive to gain superiority over western nations in many spheres of activity including science and technology. The ideological motivation that was the prime mover of this drive emphasized the development and advancement of native capabilities and the establishment of a new kind of "Soviet" science and technology. Although in some areas, this effort failed miserably (e.g., biology and cybernetics); nevertheless, on the whole, there were dramatic advances.

During this time, the Soviets were not completely oblivious to the advances of western science and technology; however, in many cases, their judgments as to the relative worth of such advances were precocious and arbitrary. Under threat of reprimand or prosecution, even the most objective Soviet scientists and engineers were obliged to accept, if not believe, these judgments. Earlier in his career, Chief Designer Korolev himself was imprisoned for suspected political-ideological misconduct[6].

This is the kind of environment in which rocket technology matured in the Soviet Union and into which the space program emerged with its immediate and profound impact on that environment. The "Sputnik" became the symbol of the Soviet claim of technological superiority which in view of its powerful impact abroad, could not have been believed any less at home. To reinforce this belief, the Soviets were consistently able to upstage the U.S. in accomplishing space "firsts". Consequently, in the Soviet perspective, it would appear that the only reasonable direction in which technology might have been transferred was from the Soviet Union to the United States and not visa versa. To the Soviets, the idea of importing U.S. space technology, which, by definition, was "inferior", would have been contrary to "reason" at best and, more than likely, was viewed as an almost absurd proposition.

This attitude probably persisted to some degree right up to 1968 when the Soviets flew an unmanned Soyuz descent module (Zond 5) on a circumlunar mission before Apollo 8 and 1969 when an unsuccessful Lunokhod mission (Luna 15) was launched two days before Apollo 11. The reality of the situation finally was established beyond dispute in the unparalleled accomplishments of the Apollo program. In view of Apollo's success, the Soviets could no longer claim technological superiority. In addition, other factors were at work which brought about a major Soviet reappraisal of their own technology and substantial changes in the political relations between the two nations. Korolev's death in 1966 and the deaths of several other leading figures (e.g., M. K. Yangle, A. M. Isayev, A. A. Blagonravov) shortly thereafter were major setbacks for the Soviet space program(17). In addition, the Soviets began to experience a long series of anomalies and failures in their Soyuz program and in their large launch vehicle programs(18). Furthermore, on the political scene, the relations between the United States and the Soviet Union changed from cold-war competitions and confrontations to detente. Accordingly, the environment and attitudes affecting the possibilities of technology transfer have changed significantly in recent years.

III. FUTURE PERSPECTIVES ON TECHNOLOGY TRANSFER

The fundamental objective of the Apollo-Soyuz Test Project is to develop and test the techniques and technology for future international space rescue capabilities[19]. The accomplishment of this objective would entail the standardization of future spacecraft docking systems and docking aids and would impact the design of certain spacecraft components such as life support systems and communications equipment. In addition, some standardized spacecraft safety precautions would have to be adopted to minimize potential hazards such as pyrotechnic devices and electromagnetic radiation from radar and communications antennas[20]. Altogether, these measures could have significant impact on future spacecraft designs and, in a round-about way, could foster technology transfer. Although, potentially, the transfer could be in either direction (U.S. to U.S.S.R. or vice versa) or any of several directions (other nations might become involved), it is more likely that the net flow would be out of the United States because of the overall superiority of U.S. technology.

To some extent, this potential outflow of U.S. space technology is the price to be paid for promoting more extensive international cooperation in space, which NASA views as desirable, or perhaps, even imperative in the long range[21], and the negative effects of one must be traded off against the positive effects of the other. As a spin-off from the Apollo-Soyuz Test Project, representatives of NASA and the U.S.S.R. Academy of Sciences held preliminary discussion recently about the possibilities of future cooperative manned missions. Reportedly, the Soviets expressed a great deal of interest in joint missions using NASA's space shuttle which is scheduled to become operational in the early-1980's[22]. Perhaps this interest is a manifestation of the large launch vehicle technology problems that the Soviets have been experiencing recently[18], problems that have hindered the progress of the Soviet earth orbital station program and precluded the undertaking of more ambitious manned missions. As indicated previously, the Soviets are also faced with serious technological constraints in crucial areas such as electronics, instrumentation, and computer technology.

In view of these problems, the Soviets may be considering the proposition that international cooperation is a viable way of coping with or circumventing the shortcomings in their native technology that have cropped up recently; and, it would be especially attractive if technology transfer could be accomplished as a bonus. So far as is known, the Soviets have not yet undertaken the development of a shuttle-type launch vehicle even though such a vehicle would be beneficial to the kind of space program that the Soviets appear to be contemplating. If they do undertake such a development, there would be some useful lessons to be learned from the NASA space shuttle program.

In addition to NASA's goal of promoting international cooperation, the present environment of political detente between the U.S. and the U.S.S.R. could have a significant impact on the future possibilities of technology transfer. This environment, for example, encourages more open and cordial relations between the two nations which permits cooperative ventures such as the Apollo-Soyuz Test Project to be undertaken. Moreover, it is reported that there is evidence of a vigorous interest in the U.S. Department of State in using U.S. science and technology in a more direct role in the conduct of international diplomacy(23). This environment is in sharp contrast to the open political-ideological conflict and technological competition that engulfed the space programs during an earlier era: an era in which according to the results of this study, little or no technology transfer appears to have occurred. Accordingly, more cordial political relations between the U.S. and the U.S.S.R. appear to go hand-in-hand with space cooperation in fostering conditions that are conducive to technology transfer.

In the case of high or complex technology (e.g., space technology), the willingness of the U.S. to make its technology available appears to be a necessary condition for transfer to occur. In the future, the transfer of technology is likely to become less a matter of simply "taking" and more a matter of "giving and taking". If so, then the future possibilities of technology transfer will depend not only on the willingness of the U.S. to cooperate but also on the capabilities of the Soviets to accommodate the transfer. This is no simple matter.

High technology developed in the U.S. (or any other nation for that matter) is intimately associated with and dependent on supporting and subsidiary technologies and the unique characteristics and capabilities of U.S. high technology industries, U.S. management and control techniques, and the U.S. economic system with its private enterprise, supply and demand, profit motives, etc. Although the transfer of high technology probably is in most cases, less difficult than the original development of that technology, the problems associated with the transfer of high technology remain great. At the present, these problems remain largely undefined and unresolved; however, in the large sense, they are closely connected with the problems of the organization of complex technology programs and the management and control of those programs (e.g., the greatest lessons learned from the U.S. Apollo Program are said to be those of how to organize, manage, and control complex technology programs[24]). The experience of the Apollo-Soyuz Test Project also provides some knowledge and insights about the Soviet capabilities in these areas.

Figure 5 illustrates the basic organizational features of the Apollo-Soyuz Test Project[25]. It is integrated into NASA on the U.S. side and into the U.S.S.R. Academy of Sciences on the Soviet side. The organizational interface consists of six working groups each of which has a U.S. co-chairman and a Soviet co-chairman. The working groups are organized by functional areas as follows:

- Working Group 0. Technical Project Directors. Co-Chairmen: K. D. Byshuyev (U.S.S.R.) and G. S. Lunney (U.S.)
- Working Group 1. Mission Model, Operations Plans, Experiments, Spacecraft Integration, Trajectory, Flight Plans, Control Centers. Co-Chairmen: A. S. Yeliseyev (U.S.S.R.) and M. P. Frank (U.S.)
- Working Group 2. Guidance and Control and Docking Aids. Co-Chairmen: V. Legostayev (U.S.S.R.) and H. E. Smith (U.S.)
- Working Group 3. Docking Mechanism and Mechanical Design. Co-Chairmen: V. S. Syromyatnikov (U.S.S.R.) and R. D. White (U.S.)
- Working Group 4. Communications. Co-Chairmen: B. Nikitin (U.S.S.R.) and R. H. Dietz (U.S.)
- Working Group 5. Life Support and Crew Transfer. Co-Chairmen: Y. Dolgopolov (U.S.S.R.) and W. Guy (U.S.)

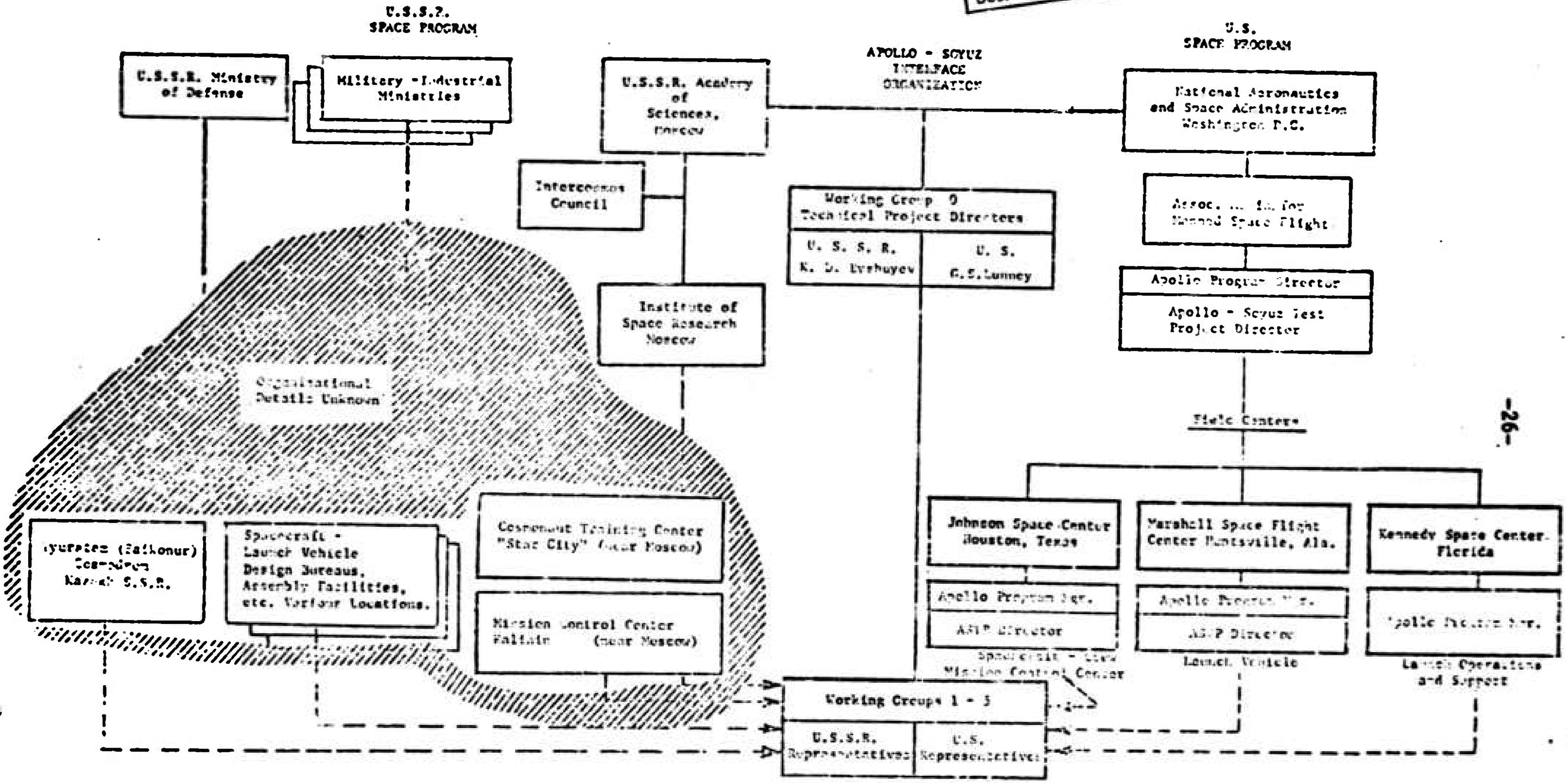

FIGURE 5. ORGANIZATIONAL FEATURES OF THE APOLLO-SOYUZ TEST PROJECT[25].

Beyond the Apollo-Soyuz Test Project (ASTP) working group level, the organization of the Soviet space program still remains obscure as indicated by the cross-hatched area on Figure 5. However, it is appropriate to consider the information that is available in connection with analyzing the processes and procedures by which foreign technology may be routinely assimilated into the Soviet system.

First-hand knowledge about the organization of the Soviet space program is limited to the U.S.S.R. Academy of Sciences and its Institute of Space Research in Moscow, the main points of contact between the U.S. and Soviet representatives involved in the Apollo-Soyuz Test Project, and several facilities visited by NASA-ASTP personnel during 1974 and 1975 including:

- The Mission Control Center, Kalinin (near Moscow); Director: A. S. Yeliseyev
- The Cosmonaut Training Center, "Star City" (Zvezdnoy Gorodok, near Moscow); Director: Unknown
- The Tyuratam (Baikonur) Cosmodrome and its support city, Leninsk, Kazakh S.S.R.; Director: Unknown.

The first two of these three facilities are the approximate Soviet equivalent of the NASA Johnson Manned Spaceflight Center at Houston, Texas, and the third is functionally comparable to the NASA Kennedy Space Center, Cape Canaveral, Florida.

The U.S.S.R. Academy of Sciences with its Intercosmos Council and Intercosmos Program, directed by Academician B. N. Petrov, and the Institute of Space Research have a relatively open role in the conduct of the Soviet space sciences program with a range of interests and projects generally comparable to those of the NASA Office of Space Science. The Soviet manned spaceflight program and some military oriented space technology programs appear to be integral with the Soviet Air Force; however, they are not listed officially as part of the Air Forces' responsibility[26]. The space applications and technology programs as well as the manufacturing and test facilities (design bureaus) appear to have organizational ties with Soviet military-industrial ministries. Overlaying the technical organizational aspects of the Soviet space program are the political-ideological controls extending downward from the highest government levels, the Council of Ministers and Communist Party Secretariat.

During the early years of the Soviet space program, the common denominator among all of these component parts was Chief Designer S. P. Korolev. However, after his death in 1966, it is not known to whom his leadership responsibilities may have passed or how they may have been allocated.

Although little is known about the organizational details of the Soviet space program it is obvious that it is organized differently from that of the U.S. and that it exists and functions in a substantially different political and economic environment. These differences have a great deal to do with the question of whether or to what extent the Soviet Union is capable of "cashing in" on U.S. space technology and how they might go about it. As suggested previously, it becomes a matter of not only acquiring the technology but also of adapting it to a different management and control structure for its useful application and, in the case of high technology (e.g., space technology), the management and control aspects of technology transfer may be the more difficult and complex.

The Soviets are well aware of these kinds of problems and devote considerable effort and resources to their solution. For example, technical innovation and technology transfer (both the assimilation of foreign technology and the dissemination of native technology) have been included as "principal problems of science and technology" in recent Soviet economic plans and the U.S.S.R. State Committee for Science and Technology is charged with the responsibility of coordinating national level efforts to improve and accelerate the application and utilization of technology[27]. It appears that in the Soviet system, centralized governmental control makes the horizontal, intra-ministerial transfer of technology an especially difficult problem. A case in point, as discussed previously, is the apparent lack of any extensive transfer of technology between the Soviet aircraft and spacecraft industries. In some respects, it appears that the introduction and dissemination of foreign technology may be less difficult in the Soviet system (because it can be managed and controlled at the "top") than the dissemination and diffusion of native technology. But, in any case, the effective management and control of high technology continues to be a problem in the Soviet Union and continues to restrict its capacity for accomplishing technology transfer on a routine basis. It should be emphasized, however, that such problems can be and sometimes have been circumvented whenever it is politically, militarily or economically expedient to do so by initiating a "crash" effort (e.g., the acquisition of German rocket technology).

Apparently, the Soviets could learn much from NASA about the management of complex technology projects and the Apollo-Soyuz Test Project provides the Soviets with some insights about NASA management techniques. It is doubtful that these techniques would be directly applicable in the Soviet political-economic environment; but, nevertheless, such knowledge would be useful if the Soviets intend to take advantage of future opportunities that appear to be opening up to then for the acquisition of U.S. technology.

IV. CONCLUSIONS

No evidence was found to indicate that technology transfer had any significant role in the historical development of Soviet space technology subsequent to their early acquisition of German rocket technology. Soviet space technology developed along independent lines with design philosophies and engineering practices that were substantially different from those of the United States. These differences together with political-ideological differences acted to surpress or constrain consideration of technology transfer options that were available to the Soviets.

However, the circumstances have changed in recent years. The most important change is believed to be a more objective and pragmatic appraisal by the Soviets of the relative status of their own technology as evidenced by the change in their official attitude regarding space cooperation (e.g., the Apollo-Soyuz Test Project). It is believed that the Soviets have accepted, at least for the time being, the fact that they need to cooperate with the United States and, if possible, to realize some technological gain out of this cooperation. Correspondingly, the current and future possibilities for technology transfer appear to be intimately connected with U.S. (NASA) policies regarding space cooperation as well as with the Soviet needs for technological assistance or support. NASA's future plans call for an emphasis on increasing the opportunities for space cooperation. The Soviet Union's long range needs appear to be great especially in areas such as electronics, instrumentation, large computers and, perhaps, propulsion. Consequently, the possibilities for technology transfer appear to be significantly greater, both now and in the future, than they were in the past. However, the transfer of this kind of technology is no simple matter and is likely to require the voluntary cooperation on the part of the possessor nation and considerable effort and expense on the part of the recipient nation.

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